Non-stationary extreme value analysis applied to seismic fragility assessment for nuclear safety analysis

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In nuclear applications, fragility curves are an essential element of the seismic probabilistic safety assessment that is performed at the level of the power plant. These statistical tools establish the link between the probabilistic seismic hazard loading at the site and the required performance of the plant's safety functions.

In the present study, we investigate the dynamic response of a supporting structure and an anchored steam line under seismic solicitations by means of the finite-element CAST3M software [1]. The failure criterion is related to the exceedance probability of the maximum equivalent stress. A coupled of hundreds of three component ground-motion records are applied at the base of the model, in order to perform non-linear time history analyses. The set of numerical results is then used to derive a vector-valued fragility function, which relates the failure probability to the variation of peak ground acceleration (PGA) and spectrum intensity (SI).

The probabilistic model of the fragility function is selected via information criteria completed by diagnostics on the residuals, which support the choice of the generalized extreme value GEV distribution (instead of the commonly used log-normal model). The GEV distribution is here non-stationary and the relationships of the GEV parameters (location, scale and shape) are established with respect to PGA and SI using Generalized Additive Models GAMs, i.e. smooth non-linear models.

The derived fragility function is however influenced by the uncertainties in the mechanical and geometrical parameters of the structures (elastic stiffness, damping, pipeline thicknesses, etc). To study the sensitivity of the fragility curve to these 10 parameters, a penalization procedure is applied to the GEV fitting process, which allows setting to zero the variables of little influence in the GAMs. One major interest of the procedure is to the ability to study the evolution of the exceedance probability as a function of the selected parameters and to identify regions of the parameters' values leading to large failure probability.

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[2] Marra, G. and S.N. Wood (2011) Practical variable selection for generalized additive models. Computational Statistics and Data Analysis 55,2372-2387.